RESIDENTIAL GROUND-SOURCE SYSTEMS

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BACKGROUND

Silence filled the room. There we were, the entire design team from the Albuquerque District of the U.S. Army Corps of Engineers, seated across the table from the Dyess Air Force Base Base Civil Engineering Team. We were discussing the 10% design for the Request For Proposals (RFP) for a design/build project to provide 179 new family housing units. Floyd Ball, Deputy Base Civil Engineer and Project Manager, broke the news. He stated that the base would shun conventional residential equipment and install ground source heat pumps in all of the new housing units. The local electrical generating utility, West Texas Utilities (WTU), and Dyess Air Force Base had collaborated to install ground source heat pumps with 67 m (220 feet) deep, closed-loop, vertical wells. This was exciting news. This was exciting engineering.

PRIOR ART

In December 1989, a nominal 10.6 kW (3 ton) GSHP with three vertical, closed-loop, 67 m (220 feet) deep wells was installed at the Guest Officers Quarters on Dyess Air Force Base. This installation initiated the collaboration between Dyess AFB and WTU. The design of the ground-loop heat exchanger was provided by the Warren W. Smith & Associates of Tulsa, Oklahoma. The GSHP installation was monitored by Texas A&M University over a three year period from July 1990 to May 1993. Attachment A contains an excerpt of this monitoring history from July 1990 to September 1990. The paper presents the data collected by the monitoring effort and the methods used to collect and analyze the data.

Long term data for this GSHP, not presented in Attachment A, indicated that the efficiency of the heat pump was decreasing[2] as shown by the following:

YEAR	SEER(Cooling)	COP(Heating)
1990	12.4	3.5
1991	11.7	3.1
1992	11.2	3.0

The gradual decrease was attributed to two factors. One, thermostat settings were lower for cooling and higher for heating for succeeding years. Two, the inclusion of air flow measurement equipment in the supply ductwork reduced incrementally reduced the flow year by year. These stated factors are confusing since the SEER was adjusted for the lower thermostat settings and unless the measurement equipment was growing is size the degree of obstruction would have remained constant. A more likely scenerio would point to a general decrease in the efficiency of the GSHP and/or the ground loop heat exchanger. It is not likely that the developing temperature profile in the soil surrounding the vertical wells is causing higher EWTs for cooling and lower EWTs for heating, because both SEER and COP were degrading with each season.

ADVANTAGES OF THE GROUND SOURCE HEAT PUMP[1]

Ground source heat pump (GSHP) systems have long been recognized as an energy efficient method of providing heating and cooling at least from an engineering standpoint. Unfortunately residential systems have not enjoyed wide acceptance. Bad press from high electric bills associated with air source heat pumps (ASHP) have made homeowners wary of the term "heat pump." However, over the past ten years GSHP systems have become more practical and more accepted as an alternative to the traditional refrigeration air conditioner and furnace.

The ASHP is a tempting substitute for the traditional heating and cooling systems. Equipment and installation costs are usually lower. The ASHP is a direct replacement for the refrigeration air conditioner with the added benefit of supplying winter heat without the cost of the furnace, gas piping, flue, or ventilation ductwork. The residential ASHP is usually an exterior padmount unit requiring little interior space facilitating the ease of installation. However, once the honeymoon is over the homeowner must settle down to life with an ASHP. Air, with its low heat capacity, in not a good source of heat. The heating efficiency of an ASHP decreases as the air temperature decreases, often requiring supplemental heat from the electric strip heater. The defrost cycle is also a kilowatt hog. The exterior units are exposed to the elements and can be noisy with the high air flowrates required for heat extraction. The attractive initial savings are quickly eaten up by the reality of higher operational costs.

While the equipment and installation costs for a GSHP system can be twice the cost of traditional heating and cooling systems, there are two main advantages over the ASHP; the earth is a stable temperature heat sink and water is an excellent heat transfer fluid. Depending on the geological formations, moisture content of soils, and water table depth the GSHP can use the relatively constant temperatures and high heat capacity of the earth as an efficient medium for heat extraction and rejection.

For residences with their similar requirements for seasonal energy rejection and extraction, there is even the possibility of storing heat in the ground during the cooling season and extracting it for the heating season and visa versa. A seasonal energy efficiency ratio (SEER) above 11 for cooling and a coefficient of performance (COP) above 3 for heating is not uncommon. While outside air temperature swings from day to day, month to month, and season to season ground temperatures below 12 m (40 feet) remain stable. This fact decouples the performance of the heat pump from the factor driving heating and cooling energy demand, outside air temperature. Of course the one item that considerably drives up the cost of GSHP is the closed-loop, earth-coupled heat exchanger. Each vertical loop or well is sized to exchange enough heat at the design flowrate (usually 11 liters per minute (3 gallons per minute)) to handle a 3.5 kW (one ton) cooling load[3]. Well depths are commonly around 60 m (200 feet). Once installed, flushed, purged of air, and pressurized the polyethylene pipe wells require little attention. The effect on the owner of a GSHP system is opposite that of the ASHP. While initial investment is high, yearly energy savings provide a payback in from 5 to 7 years over conventional heating and cooling systems.

WHY INSTALL GROUND SOURCE HEAT PUMPS AT DYESS AFB

GOVERNMENT INCENTIVES

The Department of Energy (DOE) and the Department of Defence (DoD) have collaborated on a major new initiative to expand and accelerate the use of geothermal heat pumps at military facilities. This initiative is implemented under the Congressionally mandated Strategic Environmental Research and Development Program (SERDP).

The program centers on comparative GSHP demonstrations for residential or small building installations. Monitoring of the performance of the GSHP units for a one to two year period, maintenance histories, and comparison data from conventional technologies are all funded under the initiative. Local utility assistance is encouraged.

The benefits sought by DoD include reduced maintenance costs, ease of maintenance, no outside equipment, timely payback of installed cost, energy conservation, emissions reduction, and transferability of GSHP experience to other DoD sites.

As the manager of a portion of the SERDP funds, Sandia National Laboratories (SNL) became involved in the Dyess AFB Housing Project. Support for the installation of 25 GSHPs as a demonstration project was to be provided in three ways. First, contractor funding was to be supplied to comprehensively instrument some or all of the systems to collect short and long term performance data on the GSHP hardware. Second, $1,000.00 per HVAC unit (up to 25 units) was to be provided to reduce first cost of the equipment. Third, consultation expertise was to be provided from either SNL, other DOE or DoD labs, or the International Ground Source Heat Pump Association (IGSHPA) to assist with the GSHP specifications and proposal evaluation.

In order to allow the installation of monitoring equipment to gather data on the performance of the GSHPs, SNL requested special provisions be written into the RFP as follows:

1. Separate meter sockets in the mechanical room for the GSHP and the electric domestic water heater.

2. Tee fittings in the supply and return piping of the ground loop and water heater for the installation of pressure and temperature sensors.

3. Union fittings in a vertical run of the mechanical room ground loop piping for the installation of a flowmeter.

4. A 120 VAC power outlet and enough wall space in the mechanical room to mount electronics.

5. A phone jack for modem data transfer.

WEST TEXAS UTILITIES OPENS THE DOOR

Moved by the dilemma of rising electrical demand and the cost of increasing their generating capacity, West Texas Utilities (WTU) initiated a residential energy conservation plan called Good Cents. This plan provided rate incentives for construction that met the Good Cents criteria.

A home can qualify for Good Cents certification in two different ways: Performance Method and Prescriptive Method.

The Performance Method requires the residence to meet an overall energy efficiency amount based on BTUH per square foot of conditioned space. For homes less that 125.5 square meters (1350 sq. ft.) energy efficiency cannot exceed 0.4 W/m^2 (14 BTUH/sq. ft. Homes greater than 125.5 square meters (1350 sq. ft.) cannot exceed 0.3 W/m^2 (12 BTUH/sq. ft.). If a home has a lower BTU heat gain per square foot than the standard, the home qualifies. If the heat gain is larger, the energy efficiency can be increased by adding insulation, reducing window area, or by installing thermal glazing and window tinting. Most improvements are aimed at decreasing the building cooling load and thus the electrical demand for residential air conditioning equipment.

The Prescriptive Method defines the minimum and maximum values for individual building components all aimed at producing overall energy efficiency. The Prescriptive Method list is as follows:

1. R-11 insulation for floors over a crawl space or other unheated areas.
2. R-16 wall insulation.
3. R-30 ceiling insulation and R-19 insulation for roof-ceiling combinations and knee walls.
4. Infiltration control package.
5. Insulated and weather-stripped doors.
6. Double glazed windows.
7. Adequate attic ventilation.
8. R-6 duct insulation.
9. A water heater that meets the federal appliance efficiency standards.
10. A central cooling system that meets the calculated heat gain of the entire home, but is not oversized.
    Minimum Efficiencies: Heat Pump - 11 SEER, 7 HSPF
    Geothermal - 3.1 COP

The Prescriptive Method was chosen for the new family housing units at Dyess AFB. Each of the above requirements was written into the Design/Build RFP under the architectural, mechanical, and electrical sections. With the Good Cents criteria insured by an enforceable contract, WTU offered funding assistance for the cost difference to install as many as 25 GSHP units, waste heat (desuperheater) domestic water heating, and electric supplemental water heating, to a maximum of $50,000.00. WTU agreed to provide these funds in conjunction with the DOE/DoD nation-wide initiative to install and monitor O&M performance on military installations (SERDP). The $50,000.00 was based on an estimated first cost differential for GSHP units over conventional technology equivalent to 12 SEER air conditioning and 90% AFUE space heating.

WTU essentially agreed to fund the differential cost of installing the 220 ft. deep, vertical ground-loop heat exchanger wells. Under this plan WTU worked with the General Contractor to complete ground-loop specifications and coordinate installation schedules. Funding was provided for the certified GSHP loop contractor responsible for the complete ground-loop system from the connection to the GSHP. This responsibility included the heat exchanger design, well drilling, piping installation, backfill, purging, and testing of the ground-loops. WTU also agreed to coordinate and assist DOE in planning, installing, and collecting data from the operation and maintenance of the specified homes with GSHP units and conventional HVAC equipment.

DESIGN OF THE NEW GROUND SOURCE HEAT PUMPS

The design criteria defined in the RFP set the parameters for the GSHP. Cooling capacity was sized to meet the peak cooling load calculated for the home, assuming a maximum entering water temperature (EWT) of 32.2 degrees C (90 degrees F). The heating capacity was sized at the peak heating load for an EWT for 1.7 degrees C (35 degrees F). The EWT limits determined the design of the ground loop at the recommended flow rate of 11 liters per minute (3 gallons per minute). The minimum heating or cooling capacity of the unit was set at 65,000 BTUH. The RFP set minimal design and no installation parameters for the ground loop heat exchanger. This portion of the design was handled by WTU under a separate contract. WTU provided the specification for this work. The RFP only described the interface between the work performed by Hunt Building Corp. and the well installation contractor.

CONSTRUCTION

The design/build contract was awarded to Hunt Building Corporation with Fusch, Serold & Partners, Inc. as the architect and Jensen & Associates as the mechanical/electrical designers. The design, procurement, and installation of the GSHP and wells had little effect on the overall housing project. WTU became solely responsible for the design and installation of the ground source heat exchanger wells. The RFP explicitly defined the interface between the construction performed by WTU and Hunt Building Corp.

WTU contracted with Warren W. Smith & Associates to design the closed-loop system including the depth of the wells, the size of the piping, the design of the reverse-return headers, and burial depth of the horizontal piping. The drilling contractor provided the wells, pipe installation, backfill, and well caps. Certified technicians fused all polyethylene joints as required by the International Ground Source Heat Pump Association Installation Manual. The system was filled, flushed, and purged of air, before the final connection the GSHP flow center.

Hunt Building Corp purchased and installed the GSHP units complete with flow center and supplemental domestic hot water package. They also provided the long radius pipe sleeves that stubout in the mechanical room for the ground loop piping.

THE RESULTS

Not all of the 179 family housing units received GSHPs. Supplemental funding from SERDP and WTU was more geared to the idea of a demonstration project. The final installation involved only 25 homes. Construction for the Dyess AFB family housing project was completed in September of 1995 and occupancy established as of January 1996. Dyess AFB has expressed its satisfaction with the project, but a successful housing project constructed under the design/build method can only be attributed the a unbroken chain of responsible players. Everyone did their job and did it well, from the Dyess AFB Base Civil Engineering to the Albuquerque District Corps of Engineers to West Texas Utilities to Hunt Building Corporation.

As of this date, no monitoring of the installed GSHP systems has been initiated. Sandia National Labs lost SERDP funding for the installation of instrumentation for monitoring purposes. WTU has also lost funding to carry through with a data gathering program. In short no information is presently available concerning the performance of the GSHP units. M.E.E. of El Paso, Texas holds the maintenance contract for the new housing project. Conversations with their personnel indicate low maintenance requirements and occupant satisfaction for homes with the GSHP units. Three of the ground loop systems have required further air purging to reestablish the required flowrates. No other problems have been reported.

REFERENCES

1. Command-Aire, *Earth Energy Heat Pumps, Application, Installation, Operation Manual, Bulletin C-AIO-0191*, (Command-Aire, 1988)

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